EXPERIMENTAL TEST-BED FOR INTELLIGENT PASSIVE ARRAY RESEARCH

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ABSTRACT

This document describes the test-bed designed for the investigation of passive direction finding, recognition, and classification of speech and sound sources using sensor arrays. The test-bed forms the experimental basis of the Intelligent Small-Scale Spatial Direction Finder (ISS-SDF) project, aimed at furthering digital signal processing and intelligent sensor capabilities of sensor array technology in applications such as rocket engine diagnostics, sensor health prognostics, and structural anomaly detection. This form of intelligent sensor technology has potential for significant impact on NASA exploration, earth science and propulsion test capabilities. The test-bed consists of microphone arrays, power and signal distribution modules, web-based data acquisition, wireless Ethernet, modeling, simulation and visualization software tools. The Acoustic Sensor Array Modeler I (ASAM I) is used for studying steering capabilities of acoustic arrays and testing DSP techniques. Spatial sound distribution visualization is modeled using the Acoustic Sphere Analysis and Visualization (ASAV-I) tool.

1. INTRODUCTION

During the summer of 2004, a team was assembled at NASA Stennis Space Center (SSC) to study the feasibility and begin prototype development of an intelligent passive sensor capable of identifying, quantifying and classifying the nature and source direction of a waveform. Of particular research interest is the use of signal processing techniques that estimate the waveforms of the original sources without knowing the characteristics of the source signal or transmission channel, referred to as blind signal processing (BSP) [1-3]. The initial prototype and test bed is designed around the use of microphone array sensors and forms the experimental basis of the Intelligent Small-Scale Spatial Direction Finder (ISS-SDF) project. This project, funded by the NASA Rocket Propulsion Test Management Board (RPTMB), is aimed at furthering digital signal processing and intelligent sensor capabilities of sensor array technology in applications such as rocket engine diagnostics, sensor health prognostics, and structural anomaly detection. Intelligent capabilities, in addition to the accurate estimation of transient sound source direction include; low-power optimization and adaptation, relative self-localization, performance awareness, measurement uncertainty and confidence metrics, various requirements for use in large scale wireless sensor networks [4-7]. The acoustic pressure sensor, initially specified for the audio range, will later be adapted to other pressure and vibration sensing ranges of interest. The technology has been identified to have numerous applications for Earth Science and Propulsion Test applications such as those currently taking place at SSC. In addition, numerous valuable contributions to the NASA new vision for space exploration and research are anticipated.

The test-bed consists of multi-dimensional microphone array sensors, microphone power and signal distribution modules, a CEC webDAQ/100 unit (webDAQ) for web-based data acquisition and signal conditioning, secure wireless networking, and MATLAB® modeling software running on laptop PC's [8-9]. Sound sources are sensed by the microphone arrays, acquired and conditioned by the webDAQ, then broadcast on a secure wireless network through a router. The data is processed using the Acoustic Sensor Array Modeler I (ASAM-I) [10]. ASAM-I is a comprehensive model of an acoustic sensor array and functions as an analytical tool to study the steering capabilities of acoustic sensor arrays, and to test advanced algorithms and DSP/BSP techniques. Visualization of the spatial distribution of sound around the acoustic array is modeled using the Acoustic Sphere Analysis and Visualization (ASAV-I) tool [11].

2. ARRAY ANALYSIS AND ASSEMBLY

After preliminary consideration of multiple array geometries, three sets of equally spaced spherical microphone array configurations were considered for use [12-17]. These types of microphone configurations were considered to be the least retrained in terms of source direction estimation. Three possible array configurations are shown (Figure 1a-c).
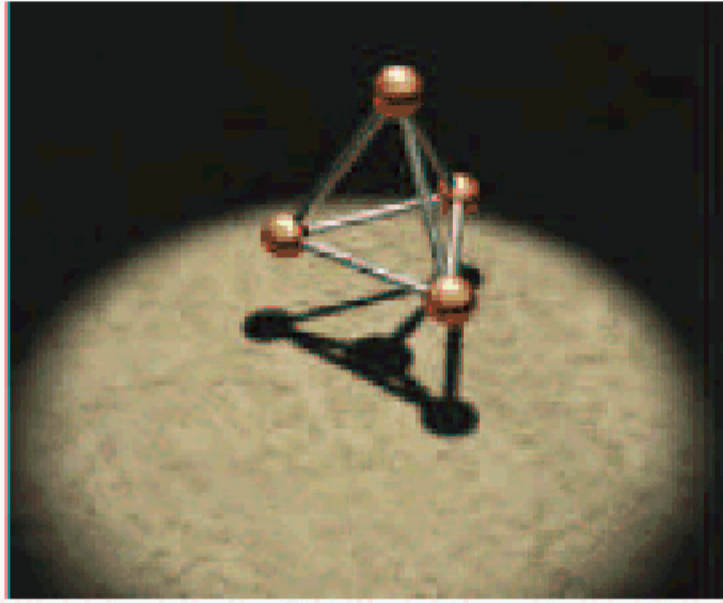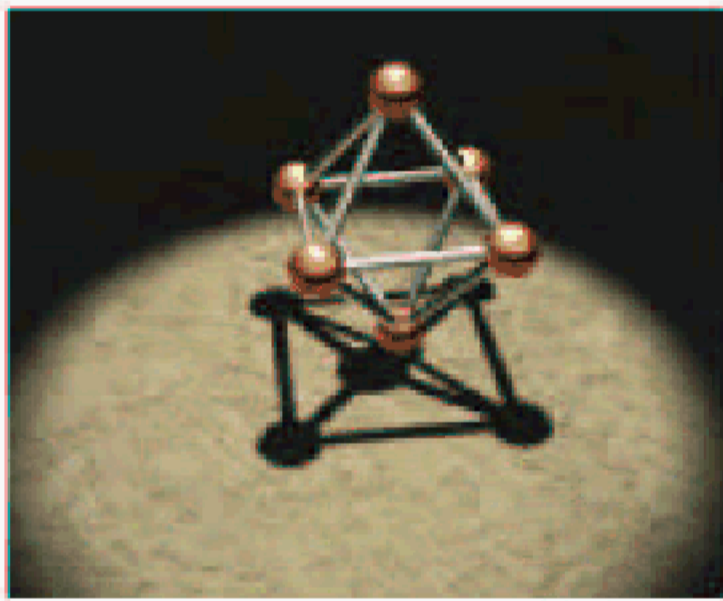

Figure 1a. Tetrahedron (4 microphones)

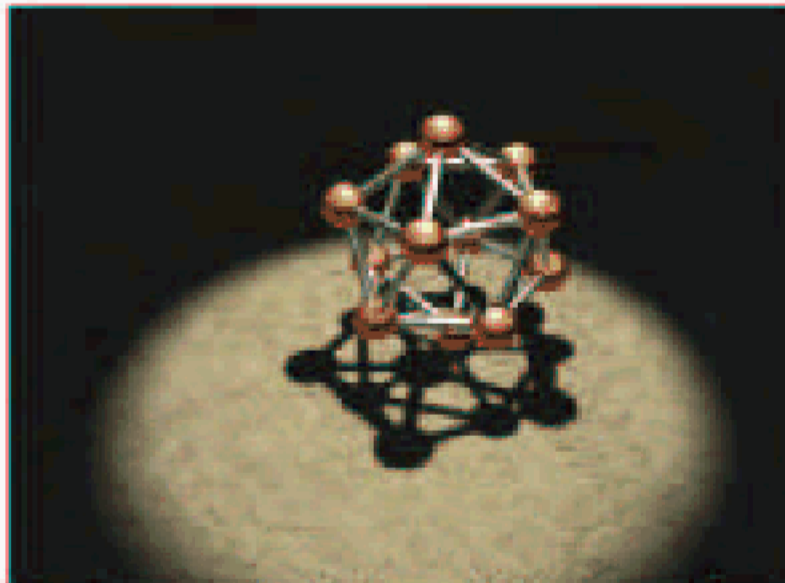Figure 1b. Octahedron (6 microphones)

Figure 1c. Icosahedron (12 microphones)

Six high gain mini-preamp and microphone packages were arranged in an octahedron configuration equally spaced from the center of the array (Figure 2-3). The signals from the six microphones were gathered by a custom-made interface circuit that provided power to the microphone array and conveniently routed the signals to the A/D converter (Figure 4).
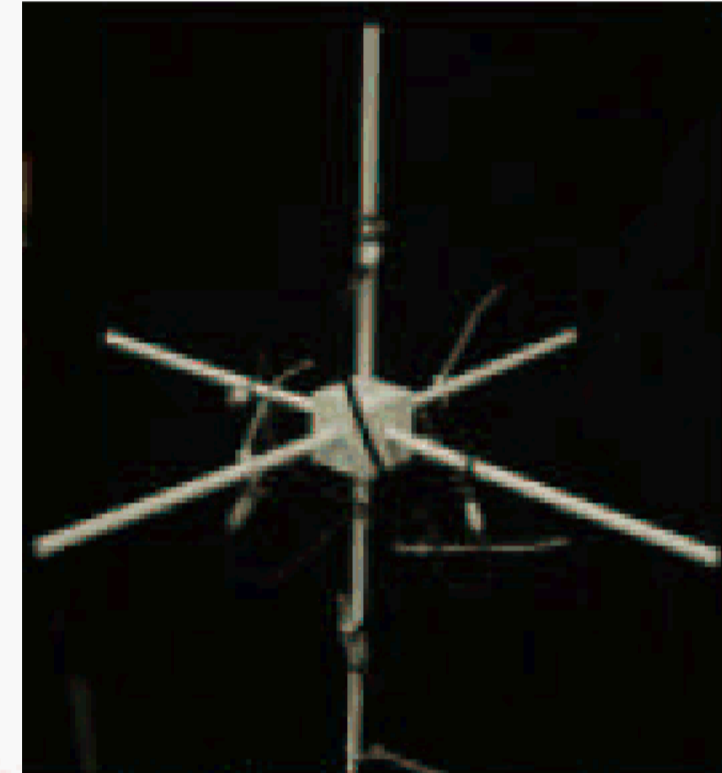

Figure 2. High gain microphone

Figure 3. Octahedron microphone array

Figure 4. Power and signal distribution module

3. SIGNAL CONDITIONING AND DATA DISTRIBUTION

The CEC webDAQ/100 unit (webDAQ) is a signal conditioning and data acquisition unit with web-based configuration and data collection (Figure 5). The unit is capable of acquiring data from up to thirty-two inputs at 500 KHz, 12 bits. The webDAQ scans channels consecutively in normal operation and distributes each channel scan equally over the entire sample period. By selecting the alternate data burst mode option, a fixed sampling rate can be achieved.

Figure 5. webDAQ/ 100

4. ONLINE MATLAB SOFTWARE INTERFACE AND ANALYSIS TOOLS

The webDAQ offers a command-based interface for altering configuration information and requesting data for off-line processing programmatically, known as the CLI. These commands enable communication from programs on a laptop to the webDAQ unit. A C-style Application Programming Interface (API), that allows C programs to interact with the webDAQ and CLI, was used to write a custom-made program to interface the WebDAQ/100 with MATLAB/Simulink for on-line analysis, and to store data for off-line processing. The WebDAQ broadcasts on a secure wireless network through a router to any number of laptop computers.

A computer- based model called Acoustic Sensor Array Modeler I (ASAM-1) has been developed in MATLAB to serve as a sensor array analysis tool. Conventional beamforming techniques, where the time signal of each microphone is selectively weighted and shifted to alter the directional response of the array, is used for initial validation of the testbed. For each point, the time delay and attenuation is computed and the array is steered toward a given point in a unit sphere encompassing the sensor array.

An additional software tool, called the Acoustic Sphere Analysis and Visualization Tool (ASAV-1) was written to graphically represent the results by coloring the surface of the unit sphere with pseudo colors representing the relative intensity of the sound as scanned by the algorithm. This sphere is called the **acoustic sphere** for the array and illustrates the intensity of the sound coming from all directions as sensed by the microphone array at a particular frequency (Figure 6). The acoustic sphere is a novel visualization tool for describing spatial distribution of sound intensity. With the use of calibrated microphones it is possible to have an accurate description of the sound pressure and its direction with respect to the microphone array. The experimental test-bed for intelligent passive array research is shown in figure 7.
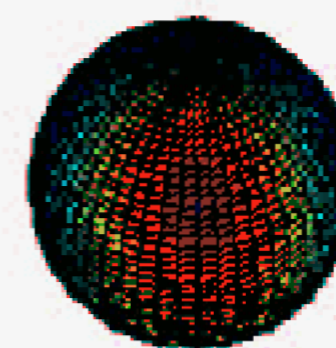

Figure 6. Acoustic Sphere

5. FUTURE WORK AND DISCUSSION

Real-time applications, such as system identification and control, usually need near instantaneous feedback. DSP processing speed therefore, must be several orders of magnitude faster than off-line algorithmic analysis. The time critical nature of the ISS-SDF requires a data acquisition and signal processing architecture supporting high instruction throughput and minimum response time to external hardware interrupts. Recently announced advanced microcontrollers with A/D and DSP preference require minimum or no communication via external bus interface [18-20]. The microcontrollers meeting requirements of fast data capture and fast data processing for support of real-time DSP/BSP applications will be investigated for use as embedded and miniaturized ISS-SDF sensor electronics.

Initial hardware prototype design and assembly of one bench-top candidate, the ADµC841 Analog Devices Microcontroller has been completed (Figure 8). This prototype system includes several wireless options including spread spectrum and cellular interfacing to external memory, dedicated DSP, a custom designed compass and a speaker driver.
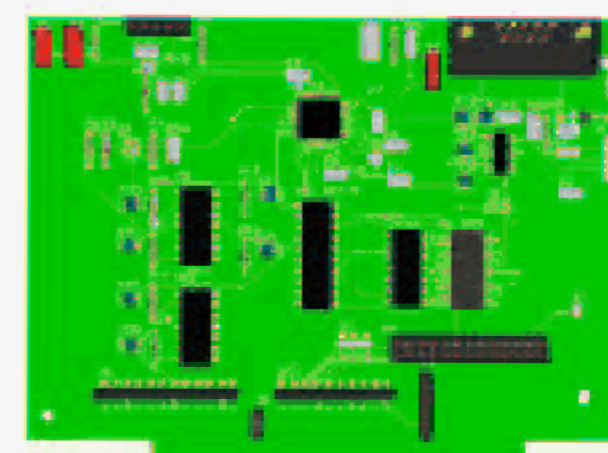

Figure 8. Microcontroller system prototype layout.

For execution of FFT and other filtering algorithms, other architectures are proposed that combine the advantages of both RISC and CISC processors. This type of CPU core, integrated with a set of powerful peripheral units and on-chip memory blocks (dedicated buses and control units), is available, along with supporting IDE, off-the-shelf.
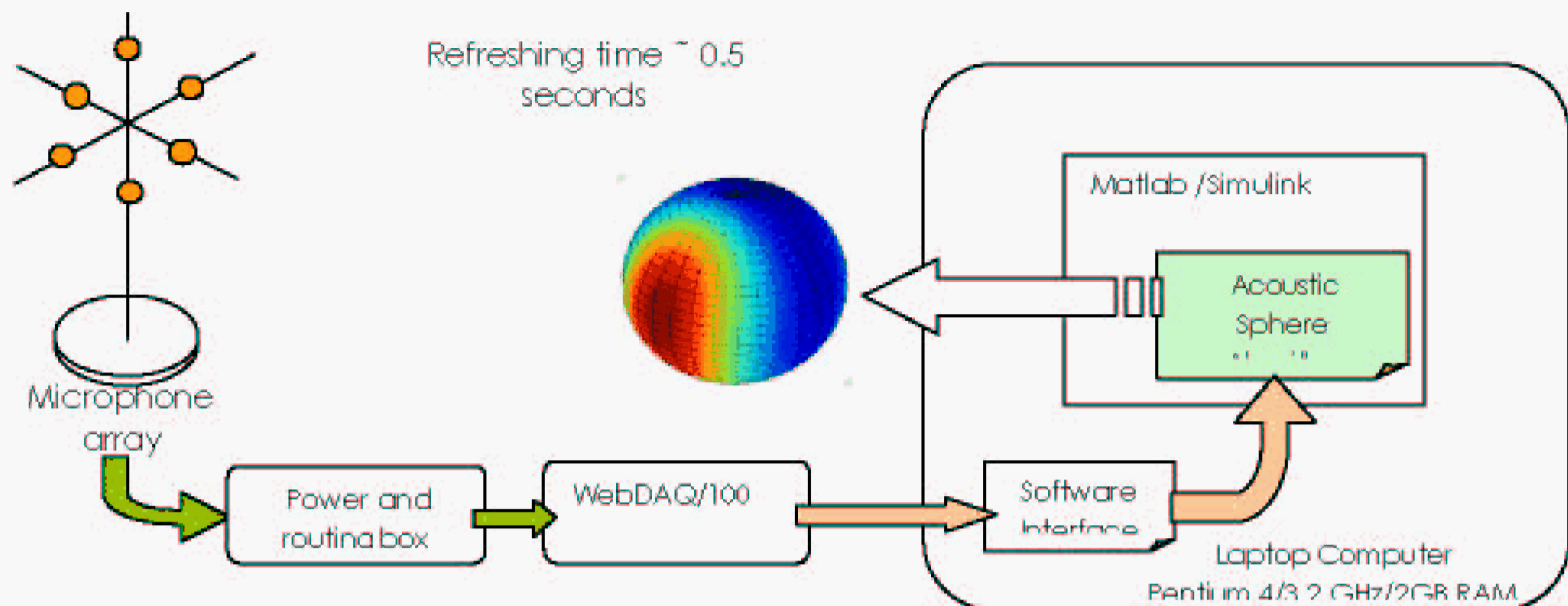
Figure 7. Experimental test-bed for intelligent passive array research

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